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TITLE CALCULATED PROTON-INDUCED THICK-TARGET NEUTRON
AND RADIONUCLIDE YIELDS FOR $E_p \leq 100$ MeV

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MASTIC

CALCULATED PROTON-INDUCED THICK-TARGET NEUTRON AND RADIONUCLIDE YIELDS FOR $E_p \leq 100$ MEV

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ABSTRACT

Earlier proton-induced thick-target yield calculations have been extended in proton energy range and to additional target elements, using the proton stopping cross section data of Anderson and Ziegler and cross sections modeled with the GNASH code. The targets now described include Be, C, O, Ne, Al, Si, Fe, Co, Ni, Cu, W, Pb and Bi. Thick-target yields are presented for these thirteen targets, with most extending to 100 MeV.

INTRODUCTION

The thick-target yields of neutrons and radioactive reaction products resulting from proton bombardment have been measured at few combinations of proton energy, target and reaction product. Such yields can be calculated with proton stopping data and reaction cross sections, but measured cross sections are available at only a few energies and for a few combinations of target and product. In earlier work we have calculated thick-target yields of particles and reaction products induced by protons below 50 MeV on various targets,^{1,2} using cross sections obtained with the GNASH nuclear model code.^{3,4} These calculations included that of aggregate neutron spectra produced in such reactions, and these were recently extended to 75 MeV.⁵ We have now extended the yield calculations to include targets of Be, Pb and Bi. Most of the targets are now described to 100 MeV.

THICK-TARGET YIELDS

The thick-target yield of proton reaction products can be calculated using the proton stopping data of Anderson and Ziegler⁶ with measured or modeled proton energy-dependent cross section functions. The expressions associated with this calculation have been developed elsewhere for α -induced thick-target yields.⁷ The central effort associated with this work is the calculation of energy-dependent proton reaction cross sections with the GNASH code.

CROSS SECTIONS

Cross sections used here have been calculated with GNASH over a period of five years, using various versions of the code as it has developed. Also, different maximum proton energies and different ranges of δN and δZ defining product nuclides were used. Unlike the work describing α -induced thick-target yields,⁷ cross sections were not calculated for all naturally occurring isotopes of each element. Of the 35 isotopes of the 13 target elements, cross sections for only 23 major isotopes were calculated; omitted were $^{17.18}\text{O}$, $^{29.30}\text{Si}$, $^{57.58}\text{Fe}$, $^{61.64}\text{Ni}$, ^{180}W and $^{204.205.207}\text{Pb}$. Cross sections were calculated for well over 1000 combinations of target nuclide and reaction product. Measured data were located describing 22 of these over at least part of the proton energy range. Comparisons of measured and calculated cross sections for three of these were selected as typical. Figure 1 compares the calculated $^{12}\text{C}(\text{p},\text{x})^{7}\text{Be}$ cross section with the data measured by Dickson and Randle⁸ and by Williams and Fulmer.⁹ Figure 2 compares the calculated $^{12}\text{C}(\text{p},\text{x})^{11}\text{C}$ cross section with the measured data of Huntz and Ramsey,¹⁰ of Whitehead and Foster,¹¹ and of Measday.¹² Figure 3 compares the calculated

$^{27}\text{Al}(\text{p},\text{x})^{22}\text{Na}$ cross section with the measured data of Hintz and Ramsey¹⁰ and of Grüitter.¹¹ These comparisons suggest an uncertainty in calculated cross section data of perhaps a factor of three for the entire range of targets, products and proton energy. Most reaction cross sections are expected to be much better, and surely some are worse.

RESULTS

The cross sections calculated with GNASH were grouped by target element, and thick-target yields were calculated for protons on each element using the natural abundances of each stable isotope; for the elements O, Si, Fe, Ni, W and Pb, abundances of the isotopes for which cross sections were calculated were renormalized from their relative abundances. In all, yields for some 688 combinations of elemental target and product particle or nuclide were calculated on a grid of proton energies. For the purpose of this paper, yields to all stable product nuclides and to all particles other than neutrons were removed from the tabulated yields; however, yields of other particles and stable product nuclides were retained and are available upon request.

The thick-target yields calculated for protons incident on the thirteen elements listed above for the production of neutrons and radionuclides are given in Tables 1 - 13 for 180 combinations of target element and product. The tables, in general, list calculated yields at 20, 40, 60, 80 and 100 MeV. Because the cross sections used in these calculations do not extend to 100 MeV for all targets considered, thick-target yields could not be calculated at all energies for all targets. Table entries of -n/c— are given for target-energy combinations not calculated.

The uncertainties associated with these calculated yields are estimated at a factor of three -- that associated with the uncertainties of the calculated cross sections as suggested in the comparisons of Figures 1 - 3.

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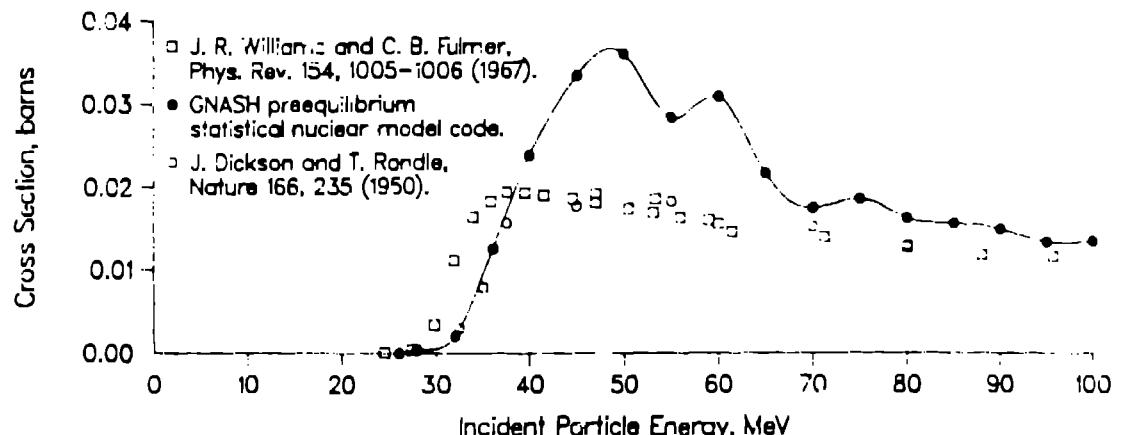


Fig. 1 Comparison of measured and GNASH calculated $^{12}\text{C}(\text{p},\text{x})^{7}\text{Be}$ cross section.

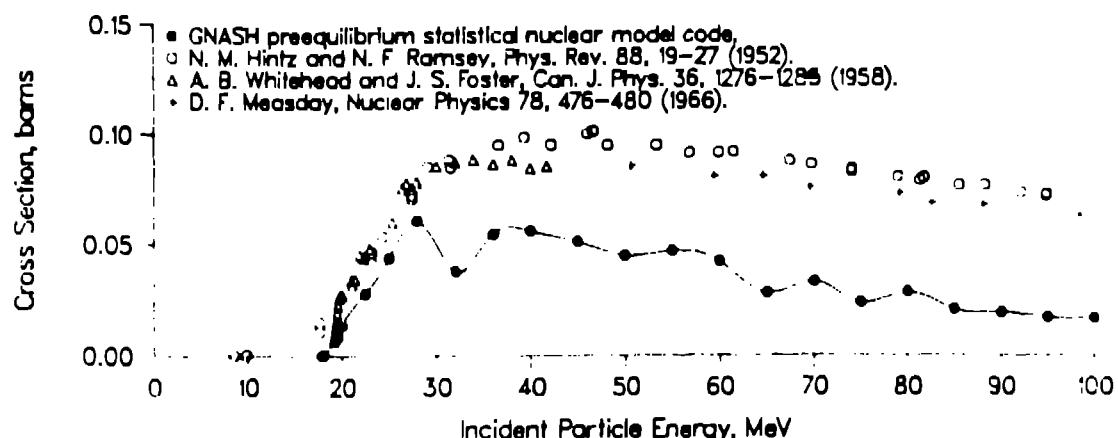


Fig. 2 Comparison of measured and GNASH calculated $^{12}\text{C}(\text{p},\text{x})^{10}\text{C}$ cross section.

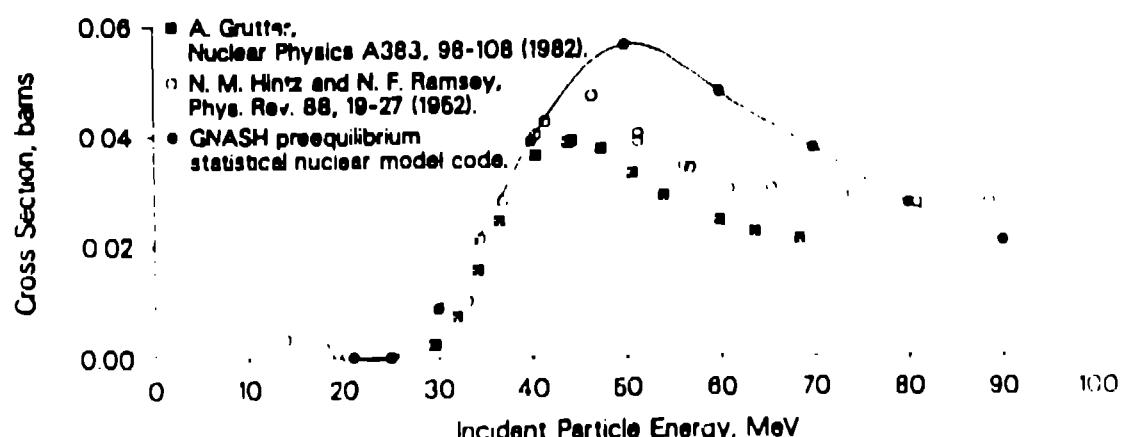


Fig. 3 Comparison of measured and GNASH calculated $^{27}\text{Al}(\text{p},\text{x})^{22}\text{Na}$ cross section

Table 1
Protons on Be Thick-Target Radionuclide Yields

Product	Incident Proton Energy				
	20 MeV	40 MeV	60 MeV	80 MeV	100 MeV
Neutron	5.71E-03	2.19E-02	5.00E-02	8.30E-02	1.22E-01
H 3	2.20E-05	2.27E-03	1.32E-02	2.75E-02	4.59E-02
H 4	0.	4.89E-08	2.38E-05	4.44E-04	4.01E-04
H 5	4.48E-03	8.89E-03	1.45E-02	1.90E-02	2.27E-02
H 6	0.	3.07E-07	7.52E-05	2.87E-04	5.50E-04
H 7	0.	1.48E-08	2.52E-06	1.27E-05	2.30E-05
H 8	0.	4.22E-06	1.1CE-04	6.41E-04	1.23E-03
H 9	2.81E-03	1.04E-02	1.87E-02	2.52E-02	3.06E-02
H 10	0.	1.73E-04	4.88E-04	7.00E-04	8.60E-04
Be 1	0.	1.83E-05	4.05E-04	8.43E-04	1.27E-03
Be 2	2.20E-05	1.48E-03	4.27E-03	6.30E-03	7.99E-03
Be 3	2.44E-03	1.09E-02	1.80E-02	2.24E-02	2.56E-02
Be 4	0.	2.77E-09	4.10E-06	1.44E-05	2.53E-05
Be 5	0.	6.36E-05	2.89E-04	4.24E-04	5.31E-04

Table 2
Protons on C Thick-Target Radionuclide Yields

Product	Incident Proton Energy				
	20 MeV	40 MeV	60 MeV	80 MeV	100 MeV
Neutron	7.63E-03	2.61E-03	1.15E-02	2.29E-02	3.91E-02
H 2	0.	8.47E-14	2.06E-05	1.51E-04	4.05E-04
H 3	6.36E-09	1.09E-05	3.99E-05	1.88E-04	5.86E-04
H 4	0.	3.88E-15	1.22E-06	1.26E-05	4.98E-05
H 5	0.	C.	1.76E-10	2.24E-08	1.64E-07
H 6	0.	3.92E-08	8.20E-05	3.19E-04	6.29E-04
H 7	0.	2.30E-04	6.15E-03	7.20E-03	8.02E-03
H 8	0.	3.86E-03	1.46E-06	8.88E-06	6.70E-05
H 9	0.	4.00E-08	1.08E-09	5.73E-07	1.15E-05
H 10	0.	0.	3.78E-18	3.06E-10	9.29E-09
Be 1	0.	0.	0.	4.33E-10	1.96E-07
Be 2	0.	7.81E-12	1.12E-05	7.57E-05	2.25E-04
Be 3	0.	3.71E-04	3.14E-03	5.48E-03	7.54E-03
Be 4	1.75E-03	4.84E-03	7.93E-03	1.14E-02	1.47E-02
Be 5	0.	1.32E-06	4.85E-05	1.14E-04	2.00E-04
Be 6	0.	2.56E-10	1.01E-07	9.70E-07	2.77E-06
Be 7	0.	0.	0.	4.84E-12	6.64E-08
Be 8	0.	9.42E-07	1.05E-05	3.90E-05	3.90E-05
Be 9	0.	3.11E-05	1.60E-04	7.14E-04	1.18E-03
Be 10	1.15E-03	2.08E-03	3.29E-03	4.07E-03	4.82E-03
Be 11	1.29E-11	4.73E-06	7.76E-06	1.02E-05	1.34E-05
Be 12	0.	0.	0.	8.45E-12	1.87E-08
Be 13	0.	4.79E-10	4.85E-07	5.32E-06	5.32E-06
Be 14	0.	3.44E-06	1.42E-04	3.57E-04	7.03E-04
N 1	2.94E-05	2.76E-03	1.00E-03	1.04E-02	1.32E-02
N 2	0.	C.	0.	4.04E-09	1.89E-07
N 3	0.	3.70E-08	1.23E-05	4.74E-05	1.45E-04
N 4	2.65E-07	1.25E-04	4.14E-04	8.16E-04	1.37E-03

Table 3
Protons on O Thick-Target Radionuclide Yields

Product	Incident Proton Energy				
	20 MeV	40 MeV	60 MeV	80 MeV	100 MeV
Neutron	1.16E-05	1.84E-05	8.40E-05	1.12E-04	1.32E-04
H 2	0.	1.58E-04	1.04E-03	1.21E-03	1.60E-03
H 3	3.96E-17	1.41E-06	3.69E-05	1.01E-04	1.90E-04
H 4	0.	0.	4.63E-19	1.01E-08	1.01E-08
H 5	0.	0.	1.42E-17	1.24E-16	4.48E-17
Be 6	0.	4.16E-17	9.47E-07	1.10E-07	1.16E-07
Be 7	0.	1.21E-19	1.14E-04	3.85E-04	1.11E-03
Be 8	2.20E-11	2.92E-02	1.53E-02	2.84E-02	4.17E-02
Be 9	0.	1.46E-10	1.40E-05	1.01E-04	1.21E-04
Be 10	0.	0.	0.	3.04E-09	2.72E-09
Be 11	0.	0.	0.	1.14E-09	1.11E-09
Be 12	0.	0.	0.	1.11E-09	1.11E-09
Be 13	0.	0.	0.	1.11E-09	1.11E-09
Be 14	0.	0.	0.	1.11E-09	1.11E-09
N 1	0.	0.	0.	1.11E-09	1.11E-09
N 2	0.	0.	0.	1.11E-09	1.11E-09
N 3	2.62E-12	6.49E-05	1.17E-04	2.57E-04	4.40E-04
N 4	0.	0.	0.	1.11E-09	1.11E-09

Table 3 (Continued)

Product	Incident Proton Energy				
	20 MeV	40 MeV	60 MeV	80 MeV	100 MeV
C 9	0.	0.	1.42E-17	9.80E-08	4.31E-06
C 10	0.	4.24E-11	7.53E-05	3.58E-04	7.67E-04
C 11	0.	1.51E-04	1.52E-03	3.12E-03	4.71E-03
C 14	0.	7.48E-05	4.57E-04	9.28E-04	1.17E-03
N 11	0.	0.	1.46E-06	9.77E-06	2.21E-05
N 12	0.	2.92E-05	2.58E-04	4.83E-04	7.42E-04
N 13	1.80E-03	2.40E-03	3.17E-03	4.35E-03	5.59E-03
O 13	0.	0.	6.56E-08	2.32E-06	8.26E-06
O 14	0.	1.06E-04	6.70E-04	1.17E-03	1.64E-03
O 15	9.16E-05	2.46E-03	5.49E-03	7.91E-03	9.89E-03
F 15	0.	0.	1.16E-06	1.37E-05	2.53E-05

Table 4
Protons on Ne Thick-Target Radionuclide Yields

Product	Incident Proton Energy				
	20 MeV	40 MeV	60 MeV	80 MeV	100 MeV
Neutron	1.95E-04	2.30E-03	8.08E-03	1.60E-02	2.69E-02
H 3	1.14E-05	1.41E-04	8.60E-04	2.07E-03	3.96E-03
F 9	0.	1.37E-06	3.13E-05	1.18E-04	2.87E-04
S 12	0.	2.40E-11	1.76E-07	4.78E-06	2.98E-05
B 13	0.	2.51E-16	2.80E-06	5.78E-07	3.02E-06
B 14	0.	0.	1.79E-16	2.39E-11	5.07E-09
B 15	0.	0.	0.	1.68E-11	7.59E-10
C 10	0.	1.15E-11	4.96E-06	4.99E-05	1.72E-04
C 11	0.	5.69E-07	1.00E-04	4.53E-04	1.11E-03
C 14	3.08E-12	4.83E-05	3.15E-04	7.66E-04	1.35E-03
C 15	0.	1.05E-11	2.35E-07	4.27E-06	2.02E-05
C 16	0.	0.	8.16E-08	6.84E-07	2.24E-06
C 17	0.	0.	4.40E-18	3.27E-11	2.56E-09
C 18	0.	0.	0.	1.03E-11	3.24E-10
N 11	0.	0.	7.59E-09	9.87E-07	7.18E-06
N 12	0.	1.31E-07	3.32E-05	1.45E-04	3.92E-04
N 13	2.55E-05	2.76E-04	5.80E-04	1.15E-03	1.94E-03
N 16	0.	1.55E-06	5.22E-05	1.80E-04	3.71E-04
N 17	0.	1.32E-06	1.61E-05	4.01E-05	6.85E-05
N 18	0.	0.	8.72E-10	4.15E-08	1.61E-07
N 19	0.	0.	7.63E-10	1.17E-08	3.41E-08
O 13	0.	0.	2.63E-08	1.88E-06	1.37E-05
O 14	0.	1.5E-05	1.66E-04	3.66E-04	5.65E-04
O 15	2.40E-10	1.5E-03	5.38E-03	8.74E-03	1.18E-02
O 19	0.	2.4E-08	1.38E-06	3.70E-06	6.16E-06
O 20	0.	4.54E-07	2.91E-06	5.31E-06	7.84E-06
F 15	0.	6.20E-10	3.99E-06	1.33E-05	2.53E-05
F 16	0.	7.02E-05	2.27E-04	3.56E-04	4.70E-04
F 17	1.03E-04	1.28E-04	2.26E-04	3.27E-04	4.20E-04
F 18	1.01E-05	3.78E-04	1.21E-03	1.84E-03	2.39E-03
F 20	2.42E-08	1.06E-05	4.22E-05	6.75E-05	8.89E-05
F 21	5.91E-08	8.09E-06	1.86E-05	2.70E-05	3.38E-05
Ne 16	0.	0.	1.98E-11	7.21E-09	3.60E-07
Ne 17	0.	0.	9.14E-07	3.49E-06	6.67E-06
Ne 18	0.	0.71E-05	1.51E-04	2.96E-04	4.01E-04
Ne 19	3.28E-05	9.54E-04	2.01E-03	2.82E-03	3.47E-03
Na 18	0.	0.	2.02E-09	5.36E-08	1.43E-07
Na 19	0.	9.66E-07	5.89E-06	9.71E-06	1.32E-05
Na 20	0.	1.27E-08	1.32E-07	2.40E-07	3.51E-07
Na 21	8.54E-07	1.49E-05	2.40E-05	3.04E-05	3.49E-05

Table 5
Protons on Al Thick-Target Radionuclide Yields

Product	Incident Proton Energy				
	20 MeV	40 MeV	60 MeV	80 MeV	100 MeV
Neutron	4.46E-04	7.35E-03	2.28E-02	4.84E-01	8.11E-01
H 3	0.	0.	1.34E-04	1.32E-03	1.54E-03
N 11	0.	0.	0.	1.34E-03	2.77E-03
N 12	0.	0.	1.66E-03	2.41E-03	2.77E-03
N 13	0.	4.53E-05	9.06E-06	4.11E-05	5.52E-05
N 16	0.	0.	1.12E-03	1.96E-03	2.09E-03
N 17	0.	0.	2.09E-03	2.40E-03	2.40E-03
N 18	0.	0.	1.	4.04E-02	6.76E-02
N 19	0.	0.	0.	1.39E-02	1.39E-02

Table 5 (Continued)

Product	Incident Proton Energ.				
	20 Mev	40 Mev	60 Mev	80 Mev	100 Mev
O	0.	0.	0.	0.	2.28E-10
O	0.	0.	0.	1.63E-07	1.63E-07
O	0.	0.	2.62E-07	1.42E-05	8.22E-05
O	0.	1.30E-07	3.95E-05	2.86E-04	7.79E-04
O	0.	0.	4.21E-10	4.27E-06	4.10E-05
O	0.	0.	1.97E-08	2.52E-06	1.07E-05
O	0.	0.	0.	2.66E-11	5.62E-08
O	0.	0.	0.	4.55E-11	6.69E-09
F	0.	0.	0.	0.	2.30E-10
F	0.	0.	0.	0.	1.58E-06
F	0.	0.	9.65E-09	5.14E-06	3.98E-05
F	0.	3.30E-09	4.61E-05	3.43E-04	1.47E-04
F	0.	0.	1.35E-04	5.85E-04	1.02E-03
F	0.	0.	8.27E-06	1.13E-04	2.78E-04
F	0.	2.34E-10	1.03E-05	4.78E-05	8.38E-05
F	0.	0.	7.94E-14	3.07E-07	3.19E-06
F	0.	0.	1.12E-10	1.36E-07	5.27E-07
Ne	0.	0.	0.	1.25E-12	3.06E-08
Ne	0.	0.	1.02E-12	2.42E-07	3.29E-06
Ne	0.	9.91E-14	7.19E-06	6.81E-05	1.66E-04
Ne	0.	1.34E-06	3.49E-05	1.37E-04	2.53E-04
Ne	0.	0.	2.28E-06	2.56E-05	4.94E-05
Ne	0.	7.08E-12	2.17E-06	8.96E-06	1.26E-05
Na	0.	0.	0.	3.33E-17	8.42E-09
Na	0.	0.	2.31E-13	3.16E-07	3.61E-06
Na	0.	0.	1.46E-06	1.89E-05	4.52E-05
Na	0.	1.05E-05	2.41E-04	6.06E-04	8.65E-04
Na	0.	4.59E-04	2.77E-03	4.99E-03	6.53E-03
Na	0.	5.99E-06	3.20E-04	8.05E-04	1.06E-03
Na	0.	2.22E-05	1.09E-04	1.70E-04	2.56E-04
Mg	0.	0.	0.	5.14E-09	1.27E-07
Mg	0.	0.	5.53E-08	1.07E-06	2.77E-06
Mg	0.	6.12E-07	1.58E-05	4.43E-05	6.85E-05
Mg	0.	2.51E-04	5.07E-04	7.19E-04	8.73E-04
Al	0.	0.	0.	4.66E-10	1.67E-03
Al	0.	0.	5.37E-08	1.13E-06	2.79E-06
Al	0.	1.25E-07	8.38E-06	2.08E-05	1.72E-05
Al	0.	3.67E-04	1.252E-03	2.05E-03	2.98E-03
Al	0.	3.30E-04	6.29E-03	1.11E-02	1.69E-02
Si	0.	0.	7.33E-10	4.93E-08	1.05E-07
Si	0.	6.31E-11	3.08E-07	3.45E-06	1.70E-05
Si	0.	2.01E-11	3.71E-05	1.78E-04	1.84E-03

Table 6
Protons on Si Thick-Target Radionuclide Yields

Product	Incident Proton Energy				
	20 Mev	40 Mev	60 Mev	80 Mev	
Neutron	1.81E-05	1.71E-03	7.40E-03	1.92E-02	3.57E-02
O	0.	0.	1.10E-11	1.10E-09	4.31E-07
O	0.	3.20E-08	1.26E-05	5.59E-05	1.44E-04
O	0.	0.	1.56E-19	8.47E-12	2.24E-08
O	0.	0.	2.26E-22	3.11E-11	4.17E-09
O	0.	0.	4.50E-09	4.16E-07	1.82E-06
O	0.	6.25E-08	1.22E-05	2.34E-05	3.82E-05
O	0.	0.	2.57E-07	6.42E-05	3.61E-04
O	0.	0.	2.48E-18	4.31E-06	2.46E-14
O	0.	0.	8.85E-12	3.05E-05	4.21E-04
O	0.	0.	0.	3.52E-15	3.75E-08
O	0.	0.	0.	1.46E-10	1.32E-05
Ne	0.	0.	0.	0.	6.10E-11
Ne	0.	0.	0.	0.	1.94E-06
Ne	0.	0.	1.84E-10	9.27E-07	8.41E-06
Ne	0.	2.61E-15	2.18E-05	2.22E-04	5.26E-14
Ne	0.	0.	1.54E-10	1.08E-07	4.58E-06
Ne	0.	0.	5.79E-12	1.17E-08	2.12E-07
Na	0.	0.	0.	0.	1.21E-11
Na	0.	0.	1.20E-11	1.40E-08	1.11E-07
Na	0.	1.77E-14	5.12E-06	2.19E-05	4.11E-05
Na	0.	5.55E-16	1.48E-05	1.19E-05	1.91E-04
Na	0.	0.	2.01E-08	1.14E-04	1.44E-04
Na	0.	0.	0.	1.04E-11	1.04E-11
Na	0.	0.	6.10E-14	1.17E-06	9.53E-07

Table 6 (Continued)

Product	Incident Proton Energy				
	20 Mev	40 Mev	60 Mev	80 Mev	100 Mev
Mg 20	0.	0.	0.	5.88E-20	9.05E-11
Mg 21	0.	0.	2.20E-20	7.88E-09	3.03E-07
Mg 22	0.	2.00E-16	2.31E-06	2.46E-05	6.60E-05
Mg 23	0.	2.40E-05	4.85E-04	1.11E-03	1.79E-03
A1 22	0.	0.	0.	1.08E-09	9.32E-08
A1 23	0.	0.	1.15E-06	9.24E-06	2.13E-05
A1 24	0.	6.40E-06	4.52E-05	8.94E-05	1.30E-04
A1 25	2.06E-04	2.24E-04	3.02E-04	5.53E-04	8.31E-04
A1 26	0.	7.70E-04	3.91E-03	7.59E-03	1.10E-02
S1 24	0.	0.	0.	2.32E-09	2.18E-07
S1 25	0.	0.	1.32E-08	1.29E-06	7.61E-06
S1 26	0.	3.05E-06	7.65E-05	2.13E-04	4.09E-04
S1 27	8.89E-06	1.59E-03	3.63E-03	5.79E-03	8.05E-03
P 26	0.	0.	4.17E-10	1.07E-07	7.08E-07
P 27	0.	7.63E-07	1.45E-05	4.47E-05	8.18E-05

Table 7
Protons on Fe Thick-Target Radionuclide Yields

Product	Incident Proton Energy				
	20 Mev	40 Mev	60 Mev	80 Mev	100 Mev
Neutron	2.60E-03	1.64E-02	--n/c---	--n/c---	--n/c---
Sc 47	0.	1.41E-34	--n/c---	--n/c---	--n/c---
V 46	0.	5.32E-11	--n/c---	--n/c---	--n/c---
V 47	1.63E-14	2.47E-06	--n/c---	--n/c---	--n/c---
V 48	0.	6.66E-07	--n/c---	--n/c---	--n/c---
V 49	2.16E-11	4.48E-05	--n/c---	--n/c---	--n/c---
V 50	0.	1.43E-07	--n/c---	--n/c	--n/c---
Cr 48	0.	1.23E-10	--n/c---	--n/c---	--n/c---
Cr 49	7.11E-26	1.38E-05	--n/c---	--n/c	--n/c---
Cr 51	9.14E-19	3.18E-04	--n/c---	--n/c	--n/c---
Mn 49	0.	1.89E-09	--n/c---	--n/c	--n/c---
Mn 50	2.97E-15	6.12E-06	--n/c---	--n/c	--n/c---
Mn 51	1.15E-05	6.18E-05	--n/c---	--n/c	--n/c---
Mn 52	3.01E-07	5.70E-04	--n/c---	--n/c	--n/c---
Mn 53	3.31E-04	8.59E-04	--n/c---	--n/c	--n/c---
Mn 54	1.27E-13	1.81E-03	--n/c	--n/c	--n/c
Fe 52	0.	8.75E-06	--n/c	--n/c	--n/c
Fe 53	1.60E-05	1.83E-04	--n/c	--n/c	--n/c
Fe 55	1.27E-03	7.05E-03	--n/c	--n/c	--n/c
Co 53	0.	8.91E-07	--n/c	--n/c	--n/c
Co 54	0.	2.69E-06	--n/c	--n/c	--n/c

Table 8
Protons on Co Thick-Target Radionuclide Yields

Product	Incident Proton Energy				
	20 Mev	40 Mev	60 Mev	80 Mev	100 Mev
Neutron	5.02E-03	2.87E-02	6.93E-02	--n/c---	--n/c---
H 3	1.94E-06	9.20E-05	3.40E-04	--n/c	--n/c
Sc 44	0.	0.	6.79E-15	--n/c	--n/c
Sc 46	0.	3.81E-20	1.28E-07	--n/c	--n/c
Sc 47	0.	6.26E-12	1.73E-06	--n/c	--n/c
Sc 48	0.	0.	2.74E-11	--n/c	--n/c
Sc 49	0.	1.83E-24	1.94E-09	--n/c	--n/c
Sc 50	0.	0.	4.14E-27	--n/c	--n/c
Sc 51	0.	0.	3.43E-21	--n/c	--n/c
Ti 45	0.	0.	1.77E-14	--n/c	--n/c
Ti 51	0.	0.	1.22E-09	--n/c	--n/c
Ti 52	0.	1.01E-23	9.19E-10	--n/c	--n/c
Ti 53	0.	0.	2.46E-26	--n/c	--n/c
Ti 54	0.	0.	4.69E-21	--n/c	--n/c
V 47	0.	0.	1.77E-10	--n/c	--n/c
V 48	0.	1.35E-19	1.29E-06	--n/c	--n/c
V 49	0.	1.11E-08	6.67E-05	--n/c	--n/c
V 50	0.	3.50E-07	1.99E-04	--n/c	--n/c
V 52	0.	4.31E-12	9.05E-06	--n/c	--n/c
V 53	0.	5.77E-09	5.39E-06	--n/c	--n/c
V 54	0.	0.	1.32E-10	--n/c	--n/c
V 55	0.	0.	8.83E-11	--n/c	--n/c
Cr 48	0.	0.	3.14E-13	--n/c	--n/c
Cr 49	0.	9.94E-20	5.24E-07	--n/c	--n/c

Table 8 (Continued)

Product	Incident Proton Energy				
	20 MeV	40 MeV	60 MeV	80 MeV	100 MeV
Cr 51	1.70E-11	2.03E-05	1.8CE-04	--n/c---	--n/c---
Cr 55	0.	3.06E-14	3.13E-06	--n/c---	--n/c---
Cr 56	0.	3.77E-10	8.78E-07	--n/c---	--n/c---
Mn 50	0.	0.	1.61E-12	--n/c---	--n/c---
Mn 51	0.	0.	7.74E-06	--n/c---	--n/c---
Mn 52	0.	1.16E-07	9.06E-05	--n/c---	--n/c---
Mn 53	8.86E-16	7.21E-05	1.41E-03	--n/c---	--n/c---
Mn 54	1.51E-09	4.13E-04	1.49E-03	--n/c---	--n/c---
Mn 56	0.	3.90E-06	1.35E-04	--n/c---	--n/c---
Mn 57	2.50E-17	4.45E-06	2.36E-05	--n/c---	--n/c---
Fe 51	0.	0.	1.04E-14	--n/c---	--n/c---
Fe 52	0.	0.	2.52E-06	--n/c---	--n/c---
Fe 53	0.	9.52E-07	1.63E-04	--n/c---	--n/c---
Fe 55	5.36E-05	7.82E-04	2.05E-03	--n/c---	--n/c---
Co 54	0.	0.	2.14E-07	--n/c---	--n/c---
Co 55	0.	2.72E-06	2.64E-04	--n/c---	--n/c---
Co 56	0.	4.05E-04	1.80E-03	--n/c---	--n/c---
Co 57	2.74E-06	3.76E-03	7.00E-03	--n/c---	--n/c---
Co 58	8.65E-04	5.40E-03	8.72E-03	--n/c---	--n/c---
Ni 55	0.	0.	1.22E-08	--n/c---	--n/c---
Ni 56	0.	2.28E-06	5.12E-05	--n/c---	--n/c---
Ni 57	0.	3.29E-04	6.54E-04	--n/c---	--n/c---

Table 9
Protons on Ni Thick-Target Radionuclide Yields

Product	Incident Proton Energy				
	20 MeV	40 MeV	60 MeV	80 MeV	100 MeV
Neutron	1.02E-03	8.52E-03	--n/c---	--n/c---	--n/c---
Mn 51	6.35E-12	2.10E-05	--n/c---	--n/c---	--n/c---
Mn 52	0.	8.88E-09	--n/c---	--n/c---	--n/c---
Mn 53	1.70E-09	2.70E-04	--n/c---	--n/c---	--n/c---
Mn 54	0.	1.33E-08	--n/c---	--n/c---	--n/c---
Mn 56	0.	9.15E-11	--n/c---	--n/c---	--n/c---
Mn 57	0.	1.39E-08	--n/c---	--n/c---	--n/c---
Fe 53	2.29E-21	3.86E-05	--n/c---	--n/c---	--n/c---
Fe 55	2.82E-14	1.79E-04	--n/c---	--n/c---	--n/c---
Fe 59	0.	2.06E-09	--n/c---	--n/c---	--n/c---
Fe 60	0.	2.48E-08	--n/c---	--n/c---	--n/c---
Co 54	3.02E-11	9.22E-05	--n/c---	--n/c---	--n/c---
Co 55	1.24E-04	1.74E-04	--n/c---	--n/c---	--n/c---
Co 56	9.79E-07	1.91E-03	--n/c---	--n/c---	--n/c---
Co 57	9.55E-04	4.84E-03	--n/c---	--n/c---	--n/c---
Co 58	2.19E-06	7.19E-04	--n/c---	--n/c---	--n/c---
Co 60	9.28E-18	2.08E-05	--n/c---	--n/c---	--n/c---
Co 61	3.35E-08	8.53E-06	--n/c---	--n/c---	--n/c---
Ni 56	8.02E-16	7.76E-05	--n/c---	--n/c---	--n/c---
Ni 57	1.8EE-04	1.74E-03	--n/c---	--n/c---	--n/c---
Ni 59	2.96E-04	1.85E-03	--n/c---	--n/c---	--n/c---
Cu 57	0.	9.17E-06	--n/c---	--n/c---	--n/c---
Cu 58	9.57E-05	1.52E-04	--n/c---	--n/c---	--n/c---
Cu 59	6.59E-07	3.09E-05	--n/c---	--n/c---	--n/c---
Cu 60	0.	4.66E-06	--n/c---	--n/c---	--n/c---

Table 10
Protons on Cu Thick-Target Radionuclide Yields

Product	Incident Proton Energy				
	20 MeV	40 MeV	60 MeV	80 MeV	100 MeV
Neutron	3.39E-03	2.13E-02	5.70E-02	1.13E-01	1.83E-01
Cr 49	0.	0.	6.90E-11	5.32E-06	5.60E-05
Cr 51	0.	2.62E-07	5.98E-05	1.95E-04	4.68E-04
Cr 55	0.	4.94E-12	1.10E-06	8.80E-06	2.04E-05
Cr 56	0.	3.52E-10	3.29E-07	1.10E-06	2.12E-06
Cr 57	0.	0.	5.01E-12	6.13E-09	2.46E-08
Cr 58	0.	0.	2.99E-13	2.26E-11	5.17E-10
Mn 50	0.	0.	0.	3.36E-12	2.29E-07
Mn 51	0.	0.	1.21E-13	3.93E-06	5.30E-05
Mn 52	0.	9.73E-14	4.68E-06	2.20E-04	6.79E-04
Mn 53	0.	7.00E-09	4.06E-04	1.87E-03	4.18E-03
Mn 54	0.	1.22E-04	1.15E-03	3.10E-03	6.21E-03
Mn 56	0.	1.07E-15	1.27E-04	7.60E-04	8.16E-04

Table 10 (Continued)

Product	Incident Proton Energy				
	20 MeV	40 MeV	60 MeV	80 MeV	100 MeV
Mn 57	7.63E-13	4.43E-06	2.19E-05	5.87E-05	1.56E-05
Mn 58	0.	7.12E-14	4.21E-07	2.41E-06	8.68E-06
Mn 59	0.	6.93E-11	7.45E-08	2.43E-07	8.59E-07
Mn 60	0.	0.	1.14E-20	9.52E-12	2.27E-09
Fe 51	0.	0.	0.	2.56E-11	1.86E-08
Fe 52	0.	0.	1.50E-09	3.32E-06	2.21E-05
Fe 53	0.	4.81E-13	1.55E-05	1.39E-04	3.88E-04
Fe 55	4.15E-10	3.28E-04	7.11E-04	1.40E-03	2.25E-03
Fe 59	0.	2.81E-05	1.22E-04	2.14E-04	3.02E-04
Fe 60	4.39E-11	1.05E-05	2.57E-05	4.06E-05	5.49E-05
Fe 61	0.	5.22E-19	1.25E-09	3.29E-08	1.08E-07
Fe 62	0.	5.04E-18	1.02E-10	1.45E-09	3.76E-09
Co 52	0.	0.	0.	0.	3.46E-16
Co 53	0.	0.	0.	1.49E-14	3.39E-09
Co 54	0.	0.	3.71E-15	1.87E-07	4.70E-06
Co 55	0.	6.69E-15	4.67E-06	5.63E-05	2.06E-04
Co 56	0.	2.19E-06	2.22E-04	1.01E-03	2.02E-03
Co 57	1.82E-10	5.04E-04	2.32E-03	4.57E-03	6.68E-03
Co 58	1.16E-04	1.74E-03	4.15E-03	6.42E-03	8.47E-03
Co 60	3.41E-05	5.09E-04	1.12E-03	1.71E-03	2.21E-03
Co 61	5.30E-05	3.05E-04	5.90E-04	8.56E-04	1.07E-03
Co 62	0.	2.64E-08	1.98E-06	5.79E-06	9.23E-06
Co 63	C.	7.71E-09	1.27E-07	3.05E-07	4.97E-07
Ni 53	0.	0.	0.	0.	2.39E-17
Ni 54	0.	0.	0.	2.63E-14	7.76E-11
Ni 55	0.	0.	2.51E-15	1.21E-08	1.59E-07
Ni 56	0.	1.29E-13	1.08E-06	8.20E-06	1.81E-05
Ni 57	0.	1.30E-05	9.84E-05	2.41E-04	3.59E-04
Ni 59	6.02E-04	1.35E-03	2.10E-03	2.85E-03	3.47E-03
Ni 63	1.38E-09	1.45E-04	2.95E-04	4.59E-04	6.01E-04
Cu 55	0.	0.	0.	0.	8.27E-25
Cu 56	0.	0.	0.	0.	4.38E-13
Cu 57	0.	0.	0.	2.01E-10	1.58E-08
Cu 58	0.	0.	1.50E-13	8.98E-07	3.46E-06
Cu 59	0.	5.75E-13	6.18E-06	3.20E-05	4.75E-05
Cu 60	0.	3.55E-05	3.05E-04	5.63E-04	8.10E-04
Cu 61	1.09E-09	1.10E-03	1.95E-03	2.60E-03	3.16E-03
Cu 62	7.61E-04	2.80E-03	4.36E-03	5.65E-03	6.91E-03
Cu 64	1.78E-04	8.23E-04	1.30E-03	1.70E-03	2.15E-03
Zn 57	0.	0.	0.	0.	2.03E-16
Zn 58	0.	0.	0.	0.	6.12E-15
Zn 59	C.	0.	6.45E-11	1.59E-08	4.37E-08
Zn 60	0.	4.64E-14	6.72E-08	1.25E-07	1.60E-07
Zn 61	0.	3.47E-06	1.22E-05	1.53E-05	1.90E-05
Zn 62	9.22E-06	3.37E-05	4.44E-05	5.33E-05	6.00E-05
Zn 63	0.	1.50E-04	2.27E-04	2.67E-04	2.98E-04

Table 11
Protons on W Thick-Target Radionuclide Yields

Product	Incident Proton Energy				
	20 MeV	40 MeV	60 MeV	80 MeV	100 MeV
Neutron	5.11E-03	4.45E-02	--n/c---	--n/c---	--n/c---
Ta 179	0.	6.75E-09	--n/c---	--n/c---	--n/c---
Ta 180	3.78E-21	1.13E-07	--n/c---	--n/c---	--n/c---
Ta 182	1.12E-12	5.28E-08	--n/c---	--n/c---	--n/c---
Ta 183	8.42E-13	3.84E-08	--n/c---	--n/c---	--n/c---
Ta 184	1.80E-24	1.61E-09	--n/c---	--n/c---	--n/c---
Ta 185	1.19E-13	1.57E-08	--n/c---	--n/c---	--n/c---
W 178	0.	7.19E-07	--n/c---	--n/c---	--n/c---
W 179	0.	5.26E-05	--n/c---	--n/c---	--n/c---
W 181	6.80E-06	5.01E-04	--n/c---	--n/c---	--n/c---
W 185	8.34E-06	2.53E-04	--n/c---	--n/c---	--n/c---
Re 178	0.	1.61E-06	--n/c---	--n/c---	--n/c---
Re 179	0.	7.22E-04	--n/c---	--n/c---	--n/c---
Re 180	4.34E-09	1.77E-03	--n/c---	--n/c---	--n/c---
Re 181	4.89E-04	3.32E-03	--n/c---	--n/c---	--n/c---
Re 182	5.39E-04	2.85E-03	--n/c---	--n/c---	--n/c---
Re 183	7.92E-04	2.88E-03	--n/c---	--n/c---	--n/c---
Re 184	2.44E-04	1.62E-03	--n/c---	--n/c---	--n/c---

Table 12
Protons on Pb-208 Thick-Target Radionuclide Yields

Product	Incident Proton Energy				
	20 MeV	40 MeV	60 MeV	80 MeV	100 MeV
Neutron	2.98E-03	3.52E-02	1.14E-01	2.38E-01	4.06E-01
Os 191	0.	0.	1.01E-20	7.23E-12	3.65E-09
Os 193	0.	5.87E-22	4.39E-13	1.66E-10	1.32E-09
Os 194	0.	1.14E-19	3.68E-12	1.46E-10	5.05E-10
Os 195	0.	8.57E-16	1.68E-12	1.44E-11	2.99E-11
Ir 192	0.	0.	1.90E-11	4.76E-08	4.48E-07
Ir 194	0.	8.25E-13	6.78E-09	5.55E-08	9.34E-08
Ir 195	3.86E-26	1.37E-10	8.58E-09	2.69E-08	3.73E-08
Ir 196	1.27E-16	4.15E-10	5.00E-09	9.12E-09	1.13E-08
Ir 197	1.53E-12	9.27E-10	2.53E-09	3.12E-09	3.64E-09
Ir 198	0.	9.51E-17	1.63E-12	1.33E-11	2.73E-11
Pt 193	0.	0.	9.41E-23	2.40E-09	2.32E-06
Pt 197	0.	5.27E-12	1.32E-07	9.32E-07	1.83E-06
Pt 199	7.32E-16	1.18E-08	1.08E-07	2.31E-07	4.37E-07
Pt 200	3.35E-11	1.01E-07	8.81E-07	1.22E-06	2.07E-06
Pt 201	0.	1.01E-16	5.68E-12	3.41E-11	5.89E-11
Au 194	0.	0.	4.45E-12	1.67E-05	1.25E-04
Au 195	0.	0.	3.91E-06	7.77E-05	1.72E-04
Au 196	0.	8.59E-12	1.39E-05	6.22E-05	8.79E-05
Au 198	4.99E-12	4.66E-06	3.07E-05	5.09E-05	6.04E-05
Au 199	8.90E-11	1.64E-05	5.13E-05	6.79E-05	8.07E-05
Au 200	3.80E-07	2.74E-05	5.06E-05	5.83E-05	6.47E-05
Au 201	9.24E-06	4.47E-05	5.39E-05	5.80E-05	6.10E-05
Au 202	7.08E-18	1.58E-09	1.72E-08	3.97E-08	6.52E-08
Au 203	1.56E-12	6.75E-08	2.48E-07	4.31E-07	5.79E-07
Hg 195	0.	0.	0.	8.15E-12	7.49E-05
Hg 197	0.	0.	9.65E-12	8.57E-05	8.61E-04
Hg 203	1.82E-05	4.08E-04	1.07E-03	1.74E-03	2.43E-03
Hg 205	7.88E-25	6.20E-14	3.05E-12	8.84E-12	1.54E-11
Hg 206	2.48E-19	9.28E-12	7.81E-11	1.64E-10	2.37E-10
Tl 196	0.	0.	0.	5.59E-06	2.50E-03
Tl 197	0.	0.	7.68E-11	1.32E-03	6.40E-03
Tl 198	0.	0.	3.17E-05	3.90E-03	6.32E-03
Tl 199	0.	1.65E-10	2.27E-03	7.73E-03	9.56E-03
Tl 200	0.	3.44E-05	5.02E-03	6.84E-03	7.86E-03
Tl 201	0.	2.23E-03	6.37E-03	7.69E-03	8.82E-03
Tl 202	4.33E-09	4.24E-03	5.38E-03	6.29E-03	7.14E-03
Tl 204	2.15E-04	6.32E-04	1.10E-03	1.61E-03	2.10E-03
Tl 206	1.17E-11	5.92E-08	1.72E-07	2.78E-07	3.83E-07
Tl 207	7.42E-10	3.31E-08	1.05E-07	2.05E-07	3.13E-07
Pb 198	0.	0.	0.	4.82E-13	4.23E-06
Pb 199	0.	0.	0.	1.26E-07	6.58E-04
Pb 200	0.	0.	1.37E-11	2.44E-04	1.35E-03
Pb 201	0.	0.	3.48E-07	9.05E-04	1.61E-03
Pb 202	0.	4.70E-12	3.11E-04	1.10E-03	1.36E-03
Pb 203	0.	1.93E-07	1.24E-03	1.67E-03	1.88E-03
Pb 205	2.20E-09	7.73E-04	9.27E-04	1.05E-03	1.16E-03
Bi 199	0.	0.	0.	1.88E-12	5.04E-04
Bi 200	0.	0.	0.	4.36E-10	1.83E-06
Bi 201	0.	0.	5.84E-15	1.33E-06	1.09E-05
Bi 202	0.	0.	7.07E-09	3.67E-06	6.85E-06
Bi 203	0.	0.	2.75E-06	1.14E-05	1.45E-05
Bi 204	0.	1.44E-11	6.57E-06	9.32E-06	1.07E-05
Bi 205	0.	5.02E-06	1.48E-05	1.66E-05	1.79E-05
Bi 206	4.56E-12	6.22E-06	7.81E-06	8.97E-06	1.00E-05
Bi 207	1.65E-06	5.76E-06	7.67E-06	9.62E-06	1.16E-05

Table 13
Protons on Bi Thick-Target Radionuclide Yields

Product	Incident Proton Energy				
	20 MeV	40 MeV	60 MeV	80 MeV	100 MeV
Neutron	3.45E-03	3.55E-02	1.09E-01	2.24E-01	3.70E-01
Os 194	3.14E-18	7.62E-14	1.55E-11	9.90E-11	1.84E-10
Os 195	0.	1.64E-23	3.13E-14	2.37E-11	2.59E-10
Ir 195	0.	7.94E-16	3.75E-06	2.18E-06	1.20E-05
Ir 196	0.	1.63E-13	1.37E-08	3.13E-07	8.68E-07
Ir 197	2.08E-19	1.97E-12	2.76E-09	2.80E-09	6.24E-08
Ir 198	0.	4.17E-24	1.02E-14	2.83E-14	2.31E-11
Pt 197	6.80E-12	5.37E-08	9.50E-07	2.02E-07	2.06E-06

Table 13 (Continued)

Product	Incident Proton Energy				
	20 Mev	40 Mev	60 Mev	80 Mev	100 Mev
Pt 199	0.	1.11E-13	1.64E-09	2.22E-08	5.18E-08
Pt 200	9.88E-20	1.05E-11	1.07E-09	6.06E-09	1.19E-08
Pt 201	0.	6.56E-26	5.87E-16	4.17E-14	2.51E-13
Au 198	0.	4.13E-10	4.71E-06	6.21E-05	2.32E-04
Au 199	8.22E-19	1.45E-07	1.09E-05	4.33E-05	7.74E-05
Au 200	7.78E-10	3.36E-07	3.52E-06	9.17E-06	1.48E-05
Au 201	1.77E-09	2.54E-07	1.16E-06	2.29E-06	3.38E-06
Au 202	0.	2.96E-15	6.81E-11	4.51E-10	9.01E-10
Au 203	0.	2.82E-14	2.15E-11	9.06E-11	1.69E-10
Au 204	0.	0.	3.29E-21	3.02E-18	3.20E-17
Hg 203	6.64E-13	8.78E-01	8.03E-07	1.87E-06	2.88E-06
Hg 205	0.	4.97E-20	2.52E-13	3.60E-12	8.21E-12
Hg 206	0.	2.11E-17	1.54E-12	8.06E-12	1.43E-11
Tl 199	0.	3.20E-16	3.26E-06	1.38E-04	6.44E-04
Tl 200	0.	3.65E-12	2.24E-05	4.17E-04	1.31E-03
Tl 201	0.	2.84E-07	2.06E-04	8.20E-04	1.49E-03
Tl 202	0.	5.25E-05	5.42E-04	1.24E-03	1.89E-03
Tl 204	1.00E-05	2.81E-04	7.70E-04	1.30E-03	1.83E-03
Tl 206	2.45E-22	1.05E-08	1.57E-07	4.03E-07	6.43E-07
Tl 207	2.94E-14	1.09E-08	6.1dE-08	1.32E-07	2.04E-07
Pb 200	0.	2.99E-11	2.03E-03	7.71E-03	1.02E-02
Pb 201	0.	5.17E-06	3.54E-03	5.99E-03	7.08E-03
Pb 202	0.	3.43E-03	9.48E-03	1.16E-02	1.33E-02
Pb 203	2.27E-04	3.57E-03	4.91E-03	5.99E-03	7.12E-03
Pb 205	2.47E-04	7.43E-04	1.43E-03	2.28E-03	3.13E-03
B1 202	0.	0.	4.23E-08	1.99E-05	3.36E-04
B1 203	0.	2.28E-11	1.23E-04	1.75E-03	2.48E-03
B1 204	0.	3.25E-10	8.13E-04	1.36E-03	1.59E-03
B1 205	0.	1.90E-04	5.49E-04	6.71E-04	7.46E-04
B1 206	1.34E-07	4.32E-05	1.24E-04	1.71E-04	2.13E-04
B1 207	7.35E-05	1.01E-02	1.27E-03	1.55E-03	1.83E-03
B1 208	5.54E-05	1.32E-04	2.46E-04	3.46E-04	4.31E-04
Po 203	0.	0.	1.19E-04	4.06E-03	1.61E-02
Po 204	0.	0.	2.55E-06	2.15E-05	2.99E-05
Po 205	0.	1.88E-10	9.91E-06	1.64E-05	1.88E-05
Po 206	0.	3.22E-06	1.03E-05	1.32E-05	1.51E-05
Po 207	5.74E-08	4.18E-06	6.15E-06	7.28E-06	8.50E-06
Po 208	1.76E-06	7.00E-06	8.23E-06	9.13E-06	1.07E-05